Real-time Suomi-NPP Green Vegetation Fraction for Improving Numerical Weather Prediction and Situational Awareness

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ABSTRACT

Soil moisture and vegetation can have substantial impacts on the transport of heat and moisture from the land surface to the atmosphere, particularly during the warm season months. Vegetation coverage and health determines the rate of evapotranspiration (ET) in land surface models (LSMs) within numerical weather prediction (NWP) models, and can strongly affect soil moisture depletion and land-atmosphere feedbacks. Vegetation coverage is typically represented by green vegetation fraction (GVF) or leaf area index, depending on the LSM being used in the NWP model. The operational Noah LSM currently uses a monthly climatology of GVF to represent the partitioning between bare soil evaporation and ET over a vegetated surface. However, climatological depictions of vegetation coverage can substantially depart from reality, particularly during episodes of anomalous temperatures during transition seasons, prolonged drought, and/or unusual wet periods. Our objective is to improve the representation of vegetation coverage in the Noah LSM and thus, the partitioning of heat fluxes in NWP models, by utilizing satellite-based GVF in place of the default climatological depiction. This is accomplished by incorporating the real-time Visible Infrared Imaging Radiometer Suite (VIIRS) GVF product generated by NOAA/NESDIS/STAR into the NASA Land Information System (LIS) and Weather Research and Forecasting (WRF) modeling systems. A series of LIS/Noah LSM offline experiments are conducted to compare the impacts of using climatological GVF versus real-time VIIRS GVF over a multi-seasonal period from years 2012 through 2015. Impacts from substantially anomalous GVF are highlighted during this time period, such as the delayed green-up in the central and eastern U.S. associated with the cool spring of 2013. Additionally, the WRF model is run at a convection-allowing resolution for select cases during the anomalous GVF period of May 2013 to examine the sensitivity of the model to input GVF and its impacts on the evolution of low level temperature, moisture, instability, and convection/precipitation production. Select results from the offline LIS/Noah multi-seasonal simulation comparison and the WRF model case studies are presented in this extended abstract and in the accompanying poster presentation.

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1. Introduction

Soil moisture and vegetation can have substantial impacts on the transport of heat and moisture from the land surface to the planetary boundary layer, particularly during the warm season months. Vegetation coverage and health determines the rate of evapotranspiration (ET) in land surface models (LSMs) within numerical weather prediction (NWP) models, and can strongly affect soil moisture depletion and land-atmosphere feedbacks. Vegetation coverage is typically represented by green vegetation fraction (GVF) or leaf area index, depending on the LSM being used in the NWP model. The operational Noah LSM (Chen and Dudhia 2001; Ek et al. 2003) currently uses a monthly climatology of GVF to represent the partitioning between bare soil evaporation and ET over a vegetated surface. However, climatological depictions of vegetation coverage can significantly depart from reality, particularly during episodes of anomalous temperatures during transition seasons, prolonged drought, and/or unusual wet periods.

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Our objective is to improve the representation of vegetation coverage in the Noah LSM and thus, the partitioning of heat fluxes and ET in NWP models, by utilizing real-time satellite-based GVF in place of the default climatological depiction. This is accomplished by incorporating the real-time Visible Infrared Imaging Radiometer Suite (VIIRS) GVF product being generated by NOAA/NESDIS/STAR (Vargas et al. 2013) into the NASA Land Information System (LIS; Kumar et al. 2006; Kumar et al. 2007; Peters-Lidard et al. 2007) and NASA Unified-Weather Research and Forecasting (WRF; Peters-Lidard et al. 2015; Skamarock et al. 2008) modeling systems.

2. Data and Methodology

a. *NESDIS/VIIRS daily GVF product*

The VIIRS GVF retrieval algorithm uses VIIRS red (I1), near-infrared (I2), and blue (M3) bands centered at 0.640 μm, 0.865 μm, and 0.490 μm respectively, to calculate the Enhanced Vegetation Index (EVI), and derive GVF from EVI. The GVF processing system (Figure 1) generates a daily-rolling weekly GVF product through the following six steps:

i. VIIRS swath surface reflectance data from bands I1 (red), I2 (NIR), and M3 (blue) during a calendar day (0000 – 2400 UTC) are mapped to the native GVF geographic grid (0.003-degree plate carrée projection) to produce a gridded daily surface reflectance global map for each band.

ii. At the end of a 7-day period, the daily surface reflectance global maps are composited to produce a weekly surface reflectance global map using the maximum view angle adjusted Soil-Adjusted Vegetation Index (SAVI) compositing algorithm, which selects at each GVF grid cell the observation with maximum view-angle adjusted SAVI value in the 7-day period. The 7-day compositing is performed every day using the data from the previous 7 days (for daily rolling weekly composites).

iii. EVI is calculated from the daily rolling weekly composited VIIRS surface reflectance data (using VIIRS bands I1, I2 and M3).

iv. High frequency noise in EVI is reduced by applying a 15-week digital smoothing filter.

v. GVF is then computed by comparing the smoothed EVI against the global maximum EVI (EVI_∞) and global minimum EVI (EVI_0) values assuming a linear relationship between EVI and GVF.

vi. GVF is finally aggregated to 0.009 degree (1-km) and 0.036 degree (4-km) resolution grids over CONUS+ and full global domains, respectively. GVF data gaps are filled using a monthly VIIRS GVF climatology.

For this paper, we transitioned the 4-km global VIIRS GVF for use in the LIS and WRF modeling systems. Future efforts will include transitioning and testing the 1-km CONUS+ GVF product as well.
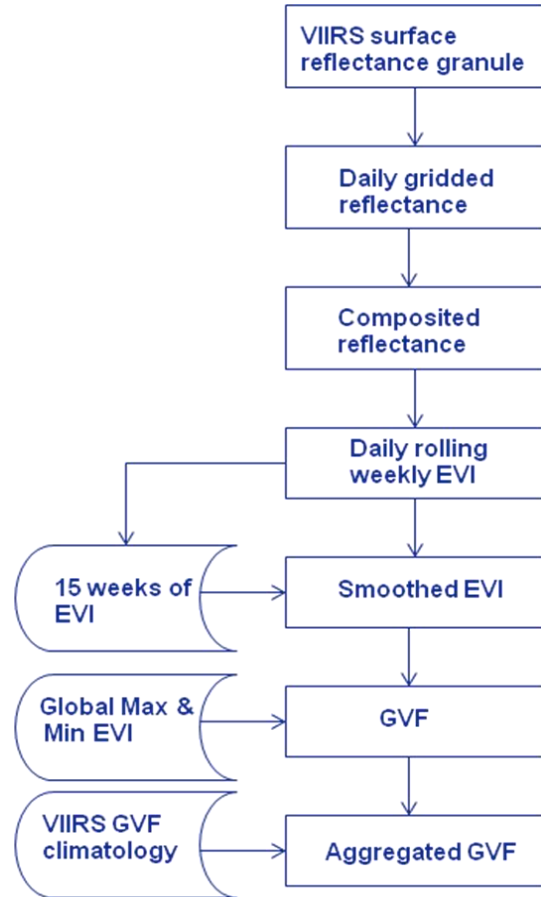

Figure 1. Flow chart of daily NESDIS/VIIRS GVF production generation.

b. *Offline LIS simulations and analysis*

Preliminary offline LIS runs were made to inter-compare the sensitivity of the LIS/Noah surface energy budget to the following four GVF datasets:

1. the legacy coarse-resolution NCEP/AVHRR GVF climatology that is the default dataset in the community WRF model and currently used in NCEP/EMC NWP models, based on NDVI data from 1985 to 1991 (Gutman and Ignatov 1998),

2. a GVF climatology derived from MODIS fraction of photosynthetically active radiation (FPAR) data from 2001-2010 (Barlage, personal communication and WRF 3.5 User's Guide [NCAR 2014]),
3. a daily 1-km real-time MODIS GVF composite produced by NASA/SPoRT over the Continental U.S. since June 2010 (Case et al. 2014), and
4. the NESDIS/VIIRS global 4-km GVF dataset.

A more comprehensive simulation comparison was then made focusing on comparing three full years (1 Sep 2012 to 31 Aug 2015) of daily VIIRS GVF to the MODIS FPAR-based GVF climatology with superior resolution and more modern data than the legacy AVHRR climatology dataset. The LIS was configured to run the Noah LSM version 3.3 over a full Continental U.S. (CONUS) domain at 0.03-deg resolution for a climatological soil moisture distribution, driven by atmospheric forcing from the North American Land Data Assimilation – Phase 2 product at NCEP/EMC (Xia et al. 2012). The soil moisture climatology comprises 34 years of daily LIS/Noah output spanning 1981 through 2014. The LIS climatology is being used to compute daily real-time soil moisture percentiles based on a daily county-by-county climatology of the full column 0-2 m relative soil moisture variable, as described in Case et al. 2015.

To analyze the details of the GVF impacts on soil moisture and surface energy fluxes, the Land surface Verification Toolkit (LVT; Kumar et al. 2012) was used to compute statistics in the simulations using the two different datasets. Statistical differences were made over each of the NCEP/EMC verification regions, as shown in Figure 2. This extended abstract presents some of the preliminary inter-comparison results of the four GVF datasets, while the poster focuses on the VIIRS/MODIS-climatology inter-comparison using LVT.

c. NU-WRF Simulations during May 2013

The NU-WRF model is configured to run at a convection-allowing resolution for select cases during a period of anomalous GVF in May 2013. These simulations enable us to examine the sensitivity of the model to anomalous input GVF relative to the MODIS GVF climatology, and its impacts on the evolution of low level temperature, moisture, instability, and convection/precipitation production. The NU-WRF model was configured to run on an identical 4-km grid as the real-time convection-allowing simulations conducted at the National Severe Storms Laboratory in

support of the NCEP Storm Prediction Center (SPC; Kain et al. 2008, 2010). The physics of the WRF model, however, are configured to use NASA-centric physics schemes developed at the Goddard Space Flight Center (GSFC). The schemes invoked include NASA/GSFC shortwave and longwave radiation schemes, Goddard 3-ice microphysics, Noah land surface model, Mellor-Yamada-Janjic boundary layer, and positive-definite advection of scalars. Refer to Peters-Lidard et al. (2015) for descriptions of the NASA physics schemes and Skamarock et al. (2008) for the community WRF model features. Select results from the WRF model case studies are highlighted in the poster presentation.
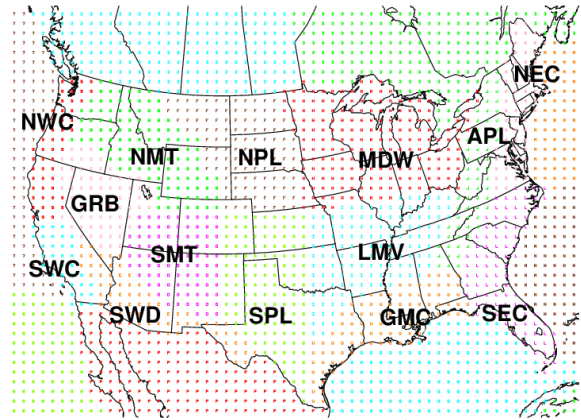

Figure 2. Depiction of the NCEP/EMC verification regions used for computing statistical differences of the 3-year VIIRS-MODIS Climatology LIS/Noah inter-comparison, using the 14 regions over the CONUS.

3. Preliminary results: LIS/Noah Inter-comparison during May 2013

A preliminary analysis of the VIIRS GVF data and output from LIS incorporating the VIIRS GVF showed that the NESDIS/VIIRS product responded reasonably to weather/climate anomalies. A monthly mean comparison between the static NCEP/GVF climatology and the real-time VIIRS GVF during May 2013 is shown in Figure 3. Spring 2013 experienced a delayed green-up of deciduous vegetation (panel b) relative to the climatological depiction (panel a), due to substantially colder than normal temperatures across much of the Continental U.S. between March and May 2013 (panel d). GVF monthly mean fractional differences of up to 40% or more are seen across portions of the Upper Midwest and Appalachians during May 2013 (panel c).

These large differences in input GVF result in notable differences in the mean surface energy fluxes and soil moisture distribution (Figure 4). Mean monthly

sensible (latent) heat flux during May 2013 increases (decreases) by more than 50 W m^{-2}, especially over the Appalachians and southern Canada (panels a and b), resulting in a corresponding change to shallow and root zone soil moisture (panels c and d). Areas of lower VIIRS GVF compared to climatology generally produce high soil moisture content, especially in the deeper root zone layers, since vegetation is not actively transpiring as aggressively with lower fractional depictions of active vegetation.
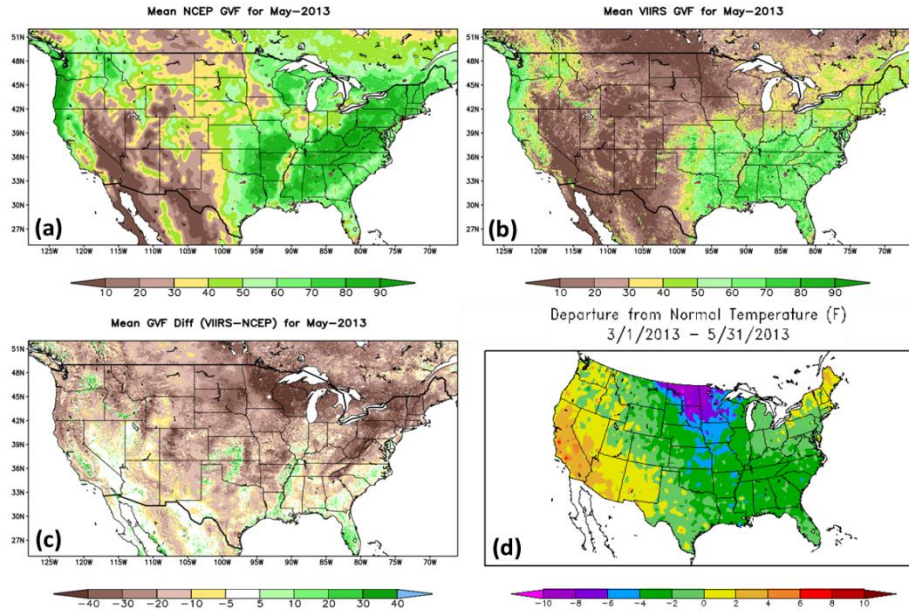

Figure 3. Comparison of GVF (%) during the delayed green-up of May 2013: (a) NCEP climatology GVF during May, (b) mean VIIRS GVF during May 2013, (c) difference in means (VIIRS – NCEP), and (d) departure from normal temperatures (deg F) from March to May 2013.
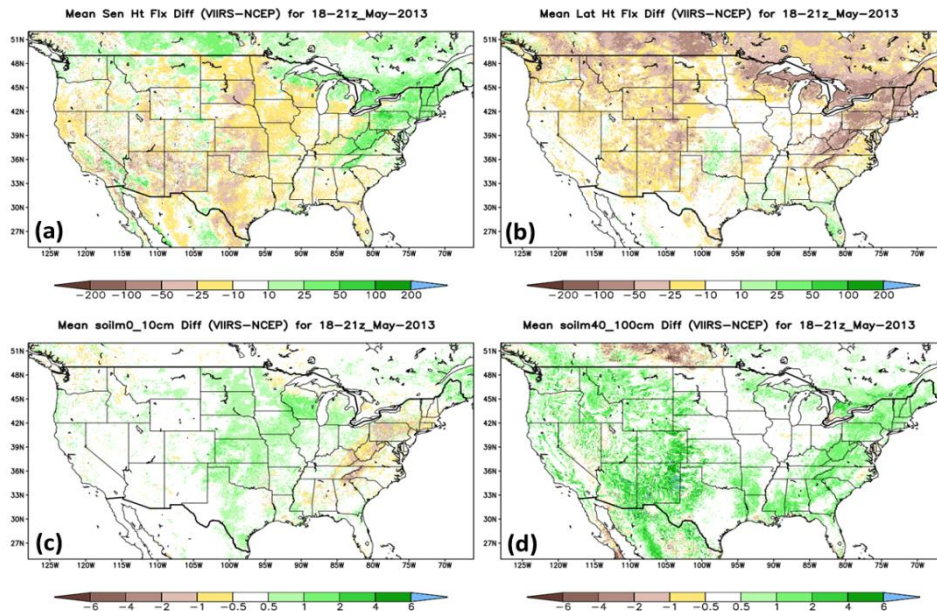

Figure 4. Mean monthly differences in heat fluxes (W m^{-2}) and volumetric soil moisture (m^{3} m^{-3}) in LIS-Noah from the 1800-2100 UTC time frame (~peak heating) during May 2013 for (a) sensible heat flux, (b) latent heat flux, (c) 0-10 cm soil moisture, and (d) 40-100 cm soil moisture.

4. Future Work

Future efforts beyond this presentation will explore verification of soil moisture and other land surface variables with the LVT to determine the accuracy the offline LSM simulations using the alternative GVF datasets. Verification shall be conducted for the WRF model case studies during May 2013 to determine if the real-time GVF produced more accurate NWP simulations during anomalous vegetation conditions.

NASA/SPoRT will work on transitioning the 1-km CONUS NESDIS/VIIRS GVF product to make the data available to NWS and other partnering agencies. SPoRT also plans to upgrade its real-time LIS simulations over eastern Africa in support of the Kenya Meteorological Service to include real-time VIIRS GVF from the global NESDIS product. This transition is expected to improve soil moisture estimates over eastern Africa, especially during anomalous dry-wet season transitions. Additionally, SPoRT will assimilate soil moisture retrievals into LIS from the NASA Soil Moisture Active Passive (SMAP) satellite, which will further improve soil moisture estimates.

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